UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES OF THE STILLING BASIN FOR THE PUMP-TURBINE BYPASS VALVE AT FLATIRON POWER AND PUMPING PLANT COLORADO-BIG THOMPSON PROJECT

Hydraulic Laboratory Report No. Hyd-328

ENGINEERING LABORATORIES BRANCH

DESIGN AND CONSTRUCTION DIVISION
DENVER, COLORADO

April 30, 1952

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Design and Construction Division
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Laboratory Report No. Hyd-328
Hydraulic Laboratory Section
Written by: L. R. Thompson
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Subject: Hydraulic model studies of the stilling basin for the pump-turbine bypass valve at Flatiron Power and Pumping Plant--Colorado-Big Thompson Project

PURPOSE

To determine a suitable stilling basin design to dissipate the energy of the jet from the pump-turbine bypass valve to prevent damage in the tailrace.

CONCLUSIONS

1. A unique stilling basin design was developed for the limited space available. It included three concrete baffles, triangular in plan, a concrete cover surmounting and extending beyond the baffles, and a water passage beneath the baffles to relieve low pressures in the basin (Figure 21). This basin will adequately dissipate the energy from a submerged jet (500 cfs at 260-foot head) of a 42-inch tube valve to give a smooth water surface in the basin (Figure 23).

2. There will be no subatmospheric pressures low enough to cause cavitation in the basin, as evidenced by a momentary minimum subatmospheric pressure of 15 feet of water in the region downstream of the center baffle (Figures 20 and 22).

3. The subatmospheric pressures downstream of the center baffle tend to become lower with a decrease in the height of baffle due to the higher circumferential velocities in the eddies downstream of the center baffle. Also, for the same reason, these pressures become lower with a decrease in the area of the exit opening between the two side baffles up to the point where this opening becomes the hydraulic control (Figures 17 and 18A).

4. Extending the cover surmounting the three basin baffles is necessary for the creation of a smooth water surface (Figures 9A and B). The cover extension had no effect on the pressures in the region around the baffles.

5. The hollow-jet valve tested with no air admitted to the low-pressure region immediately downstream from the control section of the valve needle (Figure 25) cannot safely be operated with a submerged jet because cavitation will occur.

6. For Flatiron Power and Pumping Plant, a basin design with the valve jet unsubmerged, similar to Boysen Outlet Works (Figure 5), is hydraulically inferior to a basin with a tube valve discharging with the jet submerged. For the same operating conditions the basin using a submerged jet can be smaller, there will be less spray, and the water surface will be much smoother (Figure 10).

7. Brief tests with a slide gate indicate that this gate shows promise of operating satisfactorily when the jet is submerged.

RECOMMENDATIONS

1. Use a stilling basin design with three baffles, an extended cover surmounting the baffles, a water passage beneath the baffles to relieve low pressure in the basin, and a 42-inch tube valve with the jet submerged (Figure 21).

2. Install piezometers in the region of the baffles to correlate model and prototype pressures.

ACKNOWLEDGMENT

This study was conducted jointly by engineers from the Canals Branch, the Mechanical Branch, the Structural and Architectural Branch, and the Hydraulic Laboratory of the Engineering Laboratories Branch.

INTRODUCTION

Flatiron Power and Pumping Plant, a feature of the Colorado-Big Thompson Project, is located about 9 miles west of Loveland, Colorado, between Carter Lake and Rattlesnake Reservoirs (Figure 1). The plant will contain two 48,000-horsepower turbines, one pump turbine-motor generator unit, and one bypass valve for this unit (Figures 2 and 3). Figures 2 and 3 incorporate the results of the model study reported herein. A schematic flow diagram is shown in Figure 4. Water will be released from Rattlesnake Reservoir through the 48,000-horsepower turbines for the generation of power. Part of this water will be pumped into Carter Lake by the pump-turbine unit when water is plentiful, and the rest released through the Flatiron section of the Horsetooth Feeder Canal. When Rattlesnake Reservoir is low or water is being stored in it, releases will be from Carter Lake through the pump-turbine unit for the generation of power and for supplementing water to the Flatiron section of Horsetooth Feeder Canal. In addition to the water from Carter Lake through the pump-turbine unit, it may be necessary at times to release water through the bypass to maintain the required discharge into the Flatiron section of Horsetooth Feeder Canal. In general it is expected that the pump-turbine unit will operate as a pump 16 hours a day and as a turbine during peak power requirements 8 hours a day. The only water inlet to Carter Lake is the pumped water from Flatiron Power and Pumping Plant. Carter Lake is the water source for the St. Vrain Supply Canal. Further, due to the characteristics of the pump-turbine unit, it cannot operate as a turbine at low heads, and the water released from Carter Lake to supply the Flatiron section of Horsetooth Feeder Canal under such conditions will have to be routed through the bypass valve. Also, the bypass is needed when the pump-turbine unit is shut down for maintenance or repairs.

The head on the bypass valve at a discharge of 500 cfs will be about 260 feet (Carter Lake maximum elevation minus valve elevation minus losses). The flow will vary to 500 cfs. The minimum tail-water depth on the valve centerline will be 9 feet. Constructionwise, the bypass stilling basin will be an integral part of Flatiron Power and Pumping Plant, and the space available for the basin will be limited. Consequently, the Canals Branch requested the Hydraulic Laboratory to determine the shape and size of the stilling basin required to still the bypass discharge.

The preliminary stilling basin design (including a 36-inch hollow-jet valve) was patterned after the outlet works at Boysen Dam on the Big Horn River in central Wyoming. Hydraulic model studies of the outlet works for Boysen Dam are reported in Report No. Hyd-283. A section through one of the two Boysen stilling basins is shown on Figure 5. Maximum design flow for each of the two 48-inch hollow-jet valves at Boysen was 660 cfs at 103-foot total head. Other types of valves and stilling basins were tested for the Flatiron bypass and were found more suitable than the preliminary design, so the design was changed as described in this report.

THE INITIAL MODEL

The model of the preliminary design was built on a scale of 1 to 12 and consisted of the stilling basin and a hollow-jet valve placed in a metal-lined box (Figure 6). The length ratio of model to prototype was selected so that the 36-inch hollow-jet valve could be represented by a 3-inch model which was available. Water was pumped to the model through an 8-inch pipe containing a calibrated orifice meter and a transition section from 8 to 3 inches 4 feet upstream from the hollow-jet valve. Head on the valve was measured with a mercury manometer connected to a pressure tap 1 diameter (3 inches) upstream from the valve. Tail-water elevation was controlled by a gate on the metal-lined box. The length of the basin was varied during the tests by moving the chute and valve with respect to the basin exit. The width of the basin was fixed at 9 inches (9 feet prototype) and the depth of the basin below the valve centerline at 27.8 inches (27.8 feet prototype).

STILLING BASIN FOR AN UNSUBMERGED JET

Satisfactory operation of a stilling basin like Boysen Dam Outlet Works depends upon the proper combination of length, width, and depth of the basin, valve angle, chute angle, and chute guide wall dimensions for the particular operating conditions. Since the maximum width and depth of the basin were restricted by the dimensions of the Flatiron Power and Pumping Plant, the initial problem was to determine the combination of dimensions--length, valve angle, chute angle, and chute guide walls--that, together with the predetermined depth and width, would give acceptable flow conditions.

It was apparent from the first run that the depth of the pool was insufficient to adequately cushion the valve jet. The velocity of the jet was sufficient to penetrate to the floor even without the converging chute guide walls; therefore, the addition of the converging guide walls made flow conditions worse because the guide walls caused confinement of the jet. The valve angle was varied from 24° to 30°--30° giving slightly better results than 24°. The length of the basin used in the first test was 80 inches, representing a prototype length of 80 feet. The length of the basin was increased to 96 inches to represent a prototype length of 96 feet. This length was greater than was considered acceptable, and flow conditions were not improved by the additional length. Moreover, any length greater than 24 feet required that the walls of the basin extend into the tailrace below the powerhouse, representing additional construction.

An attempt was made to disperse the jet to secure an even velocity distribution by inserting vertical bars into the basin. This flow distributor was unsuccessful for reasons that follow: If the flow area between the bars in the baffle was made small enough to give a good velocity distribution downstream of the distributor, the water upstream of the baffle overtopped the basin walls before gaining enough head to force the required discharge through the distributor openings. This difficulty could have been overcome by using several flow distributors in series with larger openings. However, the basin would be quite long since space would be required between each distributor for the dissipation of energy and the redistribution of the flow to the larger flow area.

If the jet from a valve is broken up and distributed to a larger flow area with an even velocity distribution at the exit of the basin, the velocity from the basin will not depend on the head under which the valve is discharging since from the continuity equation, the average velocity at the basin exit will equal the discharge divided by the area of the basin exit. However, to obtain an efficient energy dissipator, the discharge must leave the basin at a much lower velocity and energy level than the water in the jet entering the basin. The loss in energy is obtained by increasing the flow area with an even velocity distribution and causing the creation and destruction of many small, turbulent eddies. Since the energy in a valve jet will be proportional to the head on the valve for a given discharge, or to the square of the velocity of the jet, the stilling basin volume necessary to dissipate the major portion of the jet energy will vary roughly with the square of the velocity of the jet--if the entire volume of the stilling basin is being utilized. In the case where energy dissipators such as floor blocks, flow distributors, baffles, etc., are built into the stilling basin, the volume of basin then also becomes dependent upon the effectiveness of the dissipator configuration to create small high-velocity eddies.

Tests on the unsubmerged jet basin were discontinued due to the large size of the basin required for satisfactory flow conditions.

STILLING BASIN FOR A SUBMERGED JET

When it became apparent that the unsubmerged jet stilling basin was not suitable for Flatiron, an entirely different design was tried. It was evident from the small space available for the dissipation of the energy of the high-velocity jet that a very efficient basin from the standpoint of energy dissipated per unit volume of basin was required. This suggested a valve discharging submerged, since a submerged jet could be located near the bottom of the pool on a horizontal centerline, and thus eliminate the necessity of a chute and the waste space upstream and below the chute. A stilling basin of this type, using a tube valve discharging submerged, had been studied during model tests of methods to dissipate the high-velocity jet from the regulating valve in Tecolote Tunnel, Santa Barbara Project, California. The test results are given in Report No. Hyd-287. This basin incorporated three floor blocks, triangular in plan, surmounted by a flat, rectangular cover, extending the width of the basin, and located immediately downstream from the valve (Figure 7).

Using a Tube Valve

A submerged-valve stilling basin model was built adjacent to the unsubmerged jet basin model, using the same tail-water box so that a visual comparison could be made of the two basins operating simultaneously. A 2.8-inch outlet-diameter model tube valve was available and used to represent the 42-inch outlet-diameter tube valve in the submerged jet basin. The scale of this model basin to the prototype was 1:15.2. Whereas a 36-inch hollow-jet valve had sufficient capacity in the initial design, a larger size valve (42-inch) was now required because of the lower capacity of the tube valve.

The jet from the tube valve was discharged into the basin without floor blocks and with and without tail water to give a concept of the required energy to be dissipated (Figure 8). The first test of the basin with the floor blocks disclosed a large backroll in the basin and an uneven water surface (Figure 9A). The floor block cover was extended 24 inches, 30.4 feet prototype (Figure 9B), and the water surface became very smooth. The structure called the "cover" in the model tests represented the floor of the water-purification room in the final design of Flatiron Power and

Pumping Plant (Figure 3). It was noticed that if a gap was left between the cover on the blocks and the cover extension (Figure 9C), a backflow started over the cover extension and down through the open space, indicating a low-pressure area below the cover and downstream of the floor blocks. Therefore, a passage was provided at the bottom upstream end of the basin for the reentrance of water to the low-pressure region (Figure 9D). With floor blocks removed from the basin floor, the term "baffles" seemed more appropriate, and it is used subsequently in this report. Water would now flow up and out of the gap between the cover and over the baffles and the cover extension, instead of down through it as before, indicating a positive pressure beneath the cover. With the gap in the cover closed, the water surface again became very smooth. A comparison between the unsubmerged jet stilling basin and the submerged jet basin at comparable operating conditions is shown in Figure 10. Both basins are operating at flows representing the same prototype discharge and head.

A sheet of transparent plastic was substituted for the wooden cover surmounting the three baffles to permit a visual observation of the flow through this energy dissipator. A schematic flow diagram through the baffles is shown in Figure 11--based on visual observations. It appeared that the greatest amount of energy was dissipated in the two high-velocity eddies formed below the downstream face of the center baffle, and that the flow was distributed quite uniformly in the basin downstream from the baffles.

Basin Pressures Using a Tube Valve

The performance of the three baffles with the extended cover was considered exceptionally good based on the very smooth water surface in the basin. Proof of the structural feasibility of the design required an investigation of pressure conditions around the baffles. Of particular importance were subatmospheric pressures that might be low enough to cause damage by cavitation pitting. Although a subatmospheric pressure equal to the vapor pressure of the water must exist before cavitation can occur, a design limitation of minus 15 feet of water is often set to provide a margin of safety.

A new baffle was constructed of 16-gage sheet steel with piezometer taps located as shown in Figure 12. The piezometer taps were connected to water manometers. The model arrangement used in Test 1 is shown in Figure 13. Figure 14 contains data obtained from the test. A discharge of 500 cfs, head of 252 feet, and minimum tail-water elevation 5462, represented the prototype conditions when the lowest subatmospheric pressures would be expected (Run 1). Runs 2, 3, 4, and 5 were made to determine the trend of the pressures with an increase in head or discharge or both; however, such increases in head and discharge are not contemplated field conditions. In general, positive pressures increased and subatmospheric pressures became greater with an increase in head or discharge. In Run 1 the only subatmospheric pressures were on piezometers 8, 9, 10, and 17, which were located just downstream of the center baffle on or near the underside of the cover. The lowest pressure was at piezometer 9 which indicated a subatmospheric pressure of 4.3 feet of water prototype. The water surface in the basin remained very smooth throughout all five runs.

The effect of the backflow passage beneath the baffles on the basin pressures around the baffles was determined in Test 2 by obtaining pressures with the passage closed and minimum tail-water elevation 5462. The pressures are listed in Figure 15A. The closure of the passage lowered the pressures in general, particularly piezometer 9 which indicated a subatmospheric pressure of 7.6 feet of water as compared with 4.3 feet in Run 1 of Test 1.

For Test 3 the following changes were incorporated in the model:

(a) The valve elevation was raised from 5450.4 to 5453.0.

(b) The baffle heights were reduced from 8.5 inches (10.76 feet prototype) to 6.3 inches (7.98 feet prototype).

(c) The thickness of the slab supporting the three baffles was increased to 1.6 inches (2 feet prototype).

(d) The height of the water passage under the slab supporting the baffles was increased from 1 inch (1.27 feet prototype) to 2.6 inches (3.29 feet prototype).

(e) A 24-inch (30.4 feet prototype) extension was added to the cover surmounting the baffles.

The model arrangement for Test 3 is shown in Figure 16. The pressures obtained are listed on Figure 15B. All piezometers in Test 3 registered lower pressures than in Test 1. Part of the pressure reduction was because the effective submergence of each piezometer was reduced approximately 1 foot in Test 3 due to the higher elevation of the baffle assembly. The rest of the effect was due to the decreased height of the baffles which increased the circumferential velocities in the eddies downstream of the center baffle. Piezometer 9 again registered the lowest subatmospheric pressure, 8.7 feet (Figure 15B). The cover extension surmounting the baffles was removed. The pressures were the same with or without the cover extension.

Test 4 was conducted with same baffle assembly as Test 3, Run 1, with the exception of extensions added to the side baffles (Figure 17). The addition of these extensions lowered the pressures and the larger extensions gave the lowest pressure (Figure 18A).

The sharp, 45° corners on the two side baffles which were expected to be made of concrete on the prototype structure were considered structurally undesirable. The baffles were altered to 90° angles to increase the strength of the corners. Piezometers were installed on the downstream face of the revised baffles (Figure 19), and the pressures were determined in Test 5 (Figure 18B) with the same operating conditions as Test 4. All pressures on the face were above atmospheric, and they were approximately equal to the height of the tailwater above each piezometer. This indicated very low velocities over the downstream face of the side baffles.

For Test 6 a new baffle assembly was constructed of 16-gage sheet steel, and it contained a new set of piezometers in the most appropriate locations based on the previous test results. Piezometer locations are shown in Figure 20. The only changes in the basin design between Tests 6 and 3 were:

(a) A valve connecting sleeve was added, and

(b) The baffles were moved 1 foot further downstream.

In Test 6 the maximum subatmospheric pressure was indicated by piezometer 16 which was located about the same as piezometer 9 in Tests 1 through 4. For the most adverse conditions under which Flatiron Power and Pumping Plant would be operated (Run 1), piezometer 16 registered a subatmospheric pressure of 7.7 feet of water (Figure 18C). Run 2 at 656 cfs flow and 394-foot head was conducted to determine the trend of the pressures, and piezometer 16 again registered the lowest. The baffle assembly used in Test 6 represents the design selected for the prototype structure (Figure 21). Steel plate will be used on three faces of the center baffle and on the upstream face of the two side baffles. It is planned to install piezometers 1 through 22 in their corresponding positions in the prototype structure to determine model-prototype correlation.

A piezometer located in a region of fluctuating pressure, will indicate the average of the fluctuating pressures if the frequency of the pressure fluctuation is sufficiently high. Thus, cavitation can occur in a region where the average pressure, as indicated by a piezometer, is above the vapor pressure of the water if the minimum value of the fluctuating pressure reaches the vapor pressure of the water. To obtain the minimum value of the fluctuating pressures on the Flatiron model, pressure cells were connected to piezometers 16 and 8, and pressure-time traces were recorded by an oscillograph. The traces obtained are shown on Figure 22. The pressure on piezometer 16 varied between atmospheric and 15 feet of water below atmospheric. This pressure range is safely above cavitation pressures. The average pressures obtained from the oscillograph traces corresponded closely to the pressure readings taken with piezometers.

Analysis of Hydraulic Conditions in the Basin

The excellent flow conditions in the stilling basin using the tube valve can be attributed to the high efficiency of the three triangular baffles as an energy dissipator and flow distributor. It can be seen from the schematic flow diagram in Figure 11 that the jet from the valve was divided into two jets, which were turned 45° by the center baffle. These jets then struck the side baffles, where they turned about 90° to meet at about 90°, deflect each other and leave the side baffles in a vertical fin whose vertical dimension was limited by the floor and cover surmounting the baffles.

It is believed the greatest part of the jet energy loss occurred in the creation and continuance of the two high-velocity eddies downstream of the center baffle. The amount of energy dissipated by these eddies is a function of the velocity, diameter, and height of the eddies. A low pressure must exist at the center of an eddy to balance the centrifugal forces. The higher the peripheral velocity of the eddy, the lower the center pressure must be. A decrease of the flow area at the exit from the two side baffles (Figure 17) would lower the pressure within the eddies by increasing the velocity of the jets which in turn would increase the velocity of the eddies. An increase in the height of the baffles would decrease the velocity of the eddies, increase their height (or total areas available for friction losses), and increase the amount of energy that must be dissipated due to the decreased velocities at the exit. The net effect of increasing the baffle height, however, is to raise the pressure in the eddies.

There is a possibility (not verified by test) that the baffles can be made too high. If the baffles are so high that the jet, striking the center baffle, does not "climb" to the top of the baffle, the eddies will not form along the entire height of the downstream face of the baffle and a region of "dead" water will occur above and below the eddies. This water will be drawn into the low-pressure regions in the center of the eddies and might raise the pressure enough to reduce their effectiveness.

Excellent flow conditions existed in the basin even for heads and discharges nearly double that for the Flatiron bypass (Figure 23). At the higher heads and discharges, however, the subatmospheric pressures measured on the underside of the cover came within the cavitation range and the corresponding pressures on the floor were probably almost as low. These pressures can be raised by increasing the height of the baffles (increases flow area). In most installations the height would probably be limited by the space available, the bending stresses in the center baffle, and the fact that the baffles must be submerged by the tailwater.

The fact that cavitation produces no damage except when occurring on a surface, suggests one alternative--that of admitting large quantities of water into the low pressure region. An intermediate cover over the baffles, similar in plan area to the concrete slab supporting the baffles, could be installed. Holes cut in this cover and the concrete supporting slab at the location of the subatmospheric pressures would likely eliminate cavitation pitting from all surfaces. Water would flow into the low-pressure region through the holes which would raise the pressures. The size of the holes would have to be determined by model tests.

Using a Hollow-jet Valve

The use of a hollow-jet valve in place of the tube valve was studied since it would represent a considerable savings in initial cost. The higher capacity of the hollow-jet valve would permit the use of a smaller valve and inlet pipe (36-inch diameter as compared to 42-inch diameter). Tests were made to determine if cavitation pressures existed on a hollow-jet valve operating submerged. A 3-inch model of a standard hollow-jet valve was equipped with four piezometers just downstream of the control section on the valve needle and spaced about 90°. The model valve was operated full open with a discharge of 1.06 cfs and the centerline of the valve jet submerged 0.5 foot. The average subatmospheric pressure on the four piezometers downstream of the control section on the model needle was 5.83 feet of water. Regarding the 3-inch valve as a 1:12 scale model of a 36-inch valve, the above model data indicate that a 36-inch hollow-jet valve discharging 530 cfs with the jet centerline submerged 6 feet would create a subatmospheric pressure of 70 feet of water if such a pressure were possible. Cavitation would certainly exist under these conditions.

Two revisions of the 3-inch hollow-jet valve were tested to determine whether or not the severe subatmospheric pressures could be eliminated. The first revision consisted of a standard nozzle (body) with a cut-down needle as shown on Figure 24A. The new needle was made of wood for the model test. This valve was fixed in the full-open position and could not be closed. The model data converted to prototype values are shown on Figure 25A, which considers the 3-inch valve to be a 1:12 scale model of a 36-inch valve. The impossible pressure values given in the last column of Figure 25A show that the pressures on the valve needle were still vapor pressures and too low to be acceptable. A second revision to the valve was made, using the same cut-down needle as in the previous test and an enlarged nozzle as shown on Figure 24B. The valve was tested in the same (full-open) position. The 1:12 scale model data converted to prototype values are shown on Figure 25B. This valve, with a cut-down needle and an enlarged nozzle, was moved to the 55-percent open position. The 1:12 scale model data changed to prototype values are shown on Figure 25C. The conclusion from the above data was that the hollow-jet valve could not be safely operated with the jet submerged under the conditions of head and discharge at Flatiron Power and Pumping Plant.

Using a Slide Gate

The model tube valve was replaced by a slide gate and tested briefly. The slide gate gave satisfactory flow conditions through the baffles and basin at all openings. No data were recorded.

Interior - Reclamation - Denver, Colo.

FIGURE 1
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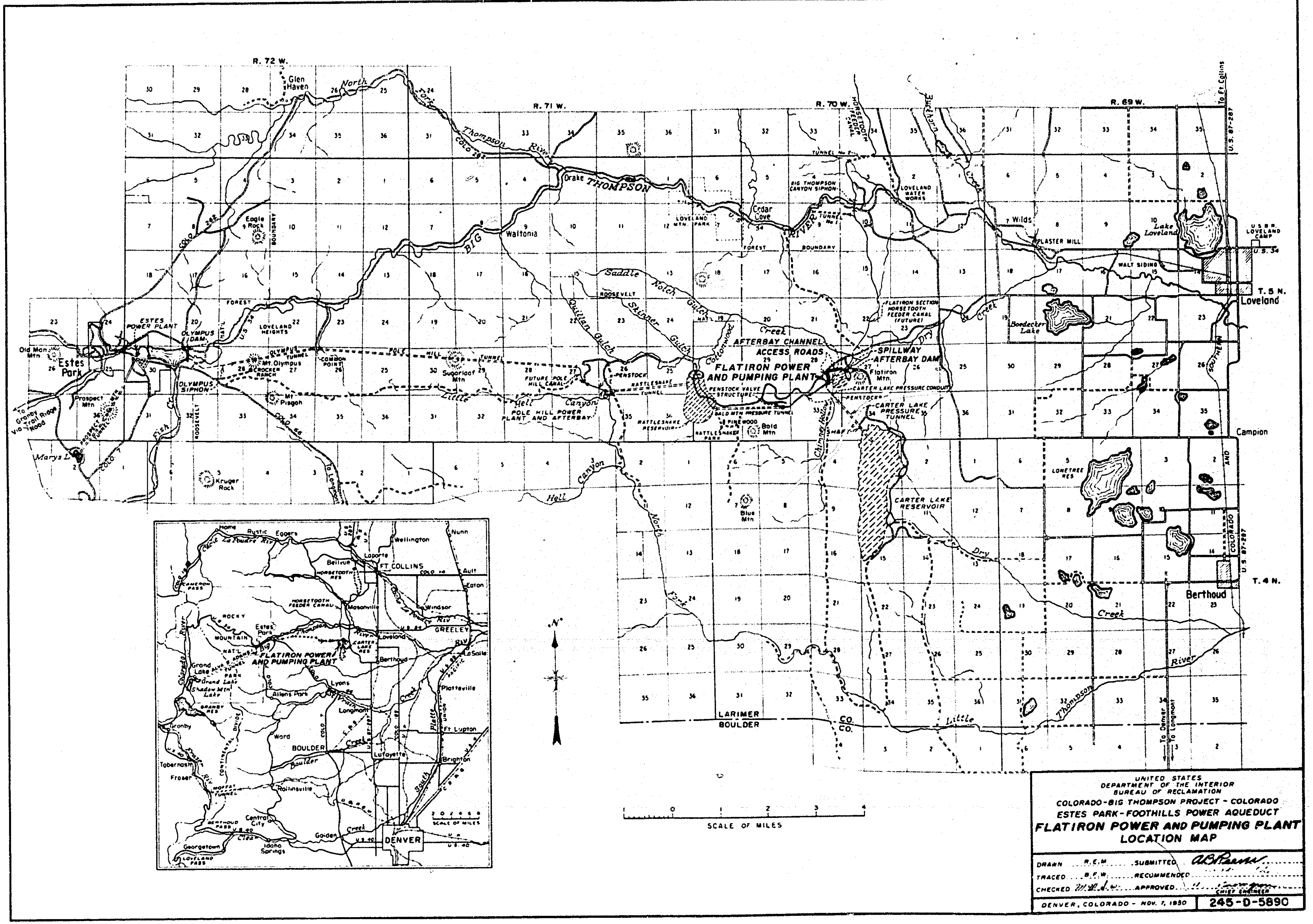
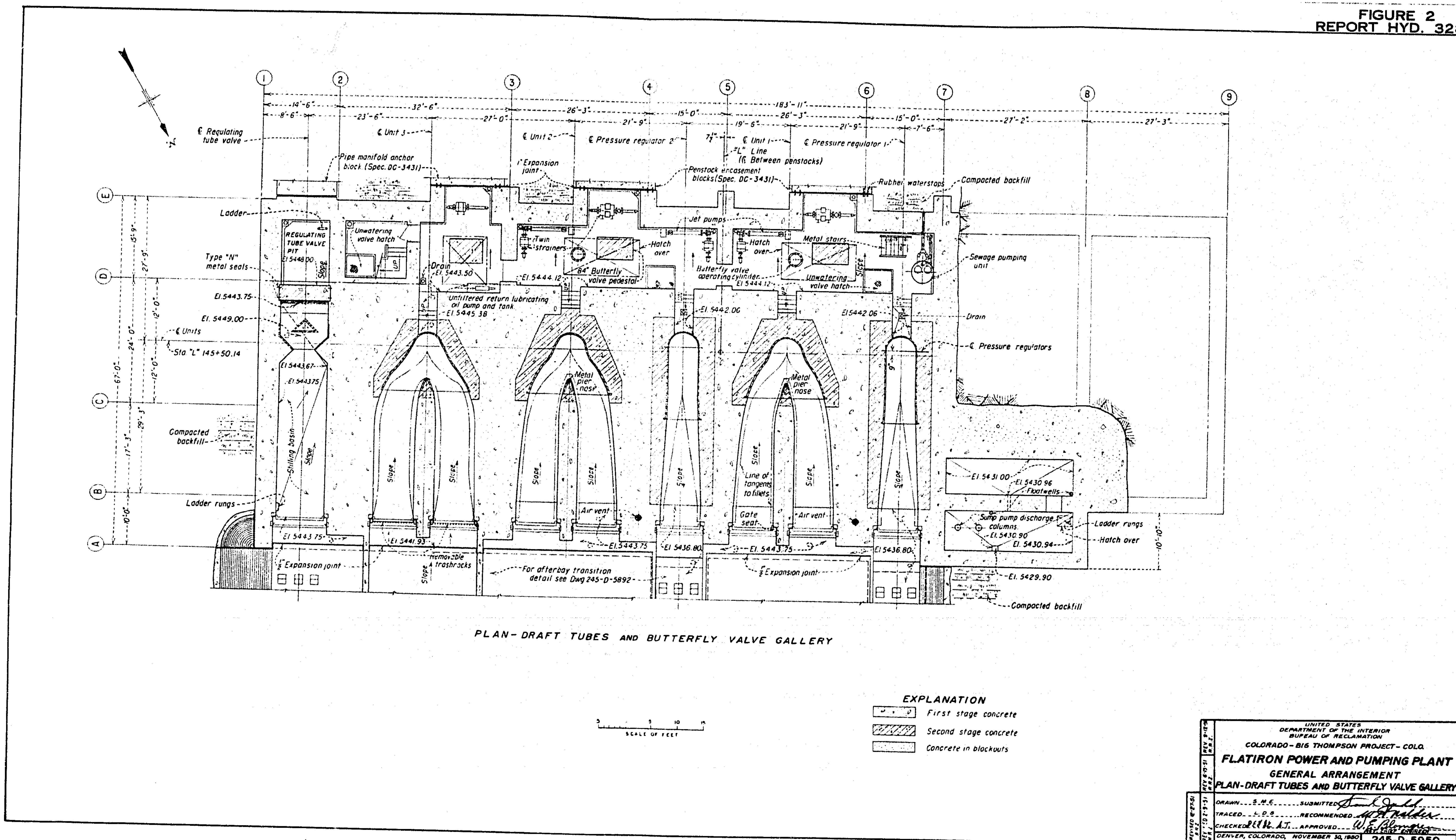
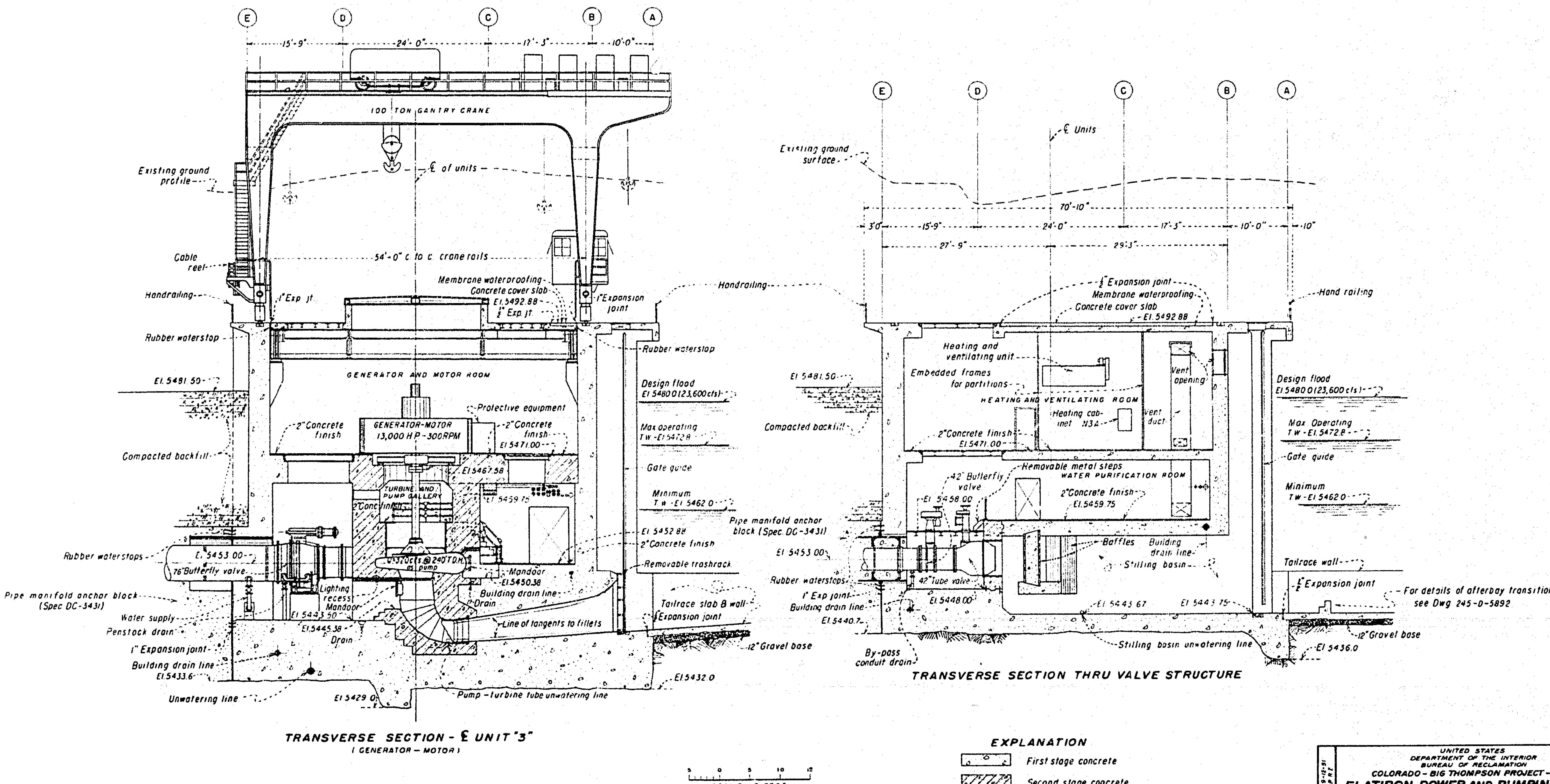



PLAN-DRAFT TUBES AND BUTTERFLY VALVE GALLERY
EXPLANATION
First stage concrete
Second stage concrete
Concrete in blockouts
SCALE OF FEET
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO-BIG THOMPSON PROJECT-COLO.
FLATIRON POWER AND PUMPING PLANT
GENERAL ARRANGEMENT
PLAN-DRAFT TUBES AND BUTTERFLY VALVE GALLERY
DENVER, COLORADO, NOVEMBER 30, 1950
245-D-5950



EXPLANATION

First stage concrete
Second stage concrete
Concrete in blockouts

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO - BIG THOMPSON PROJECT - COLO.

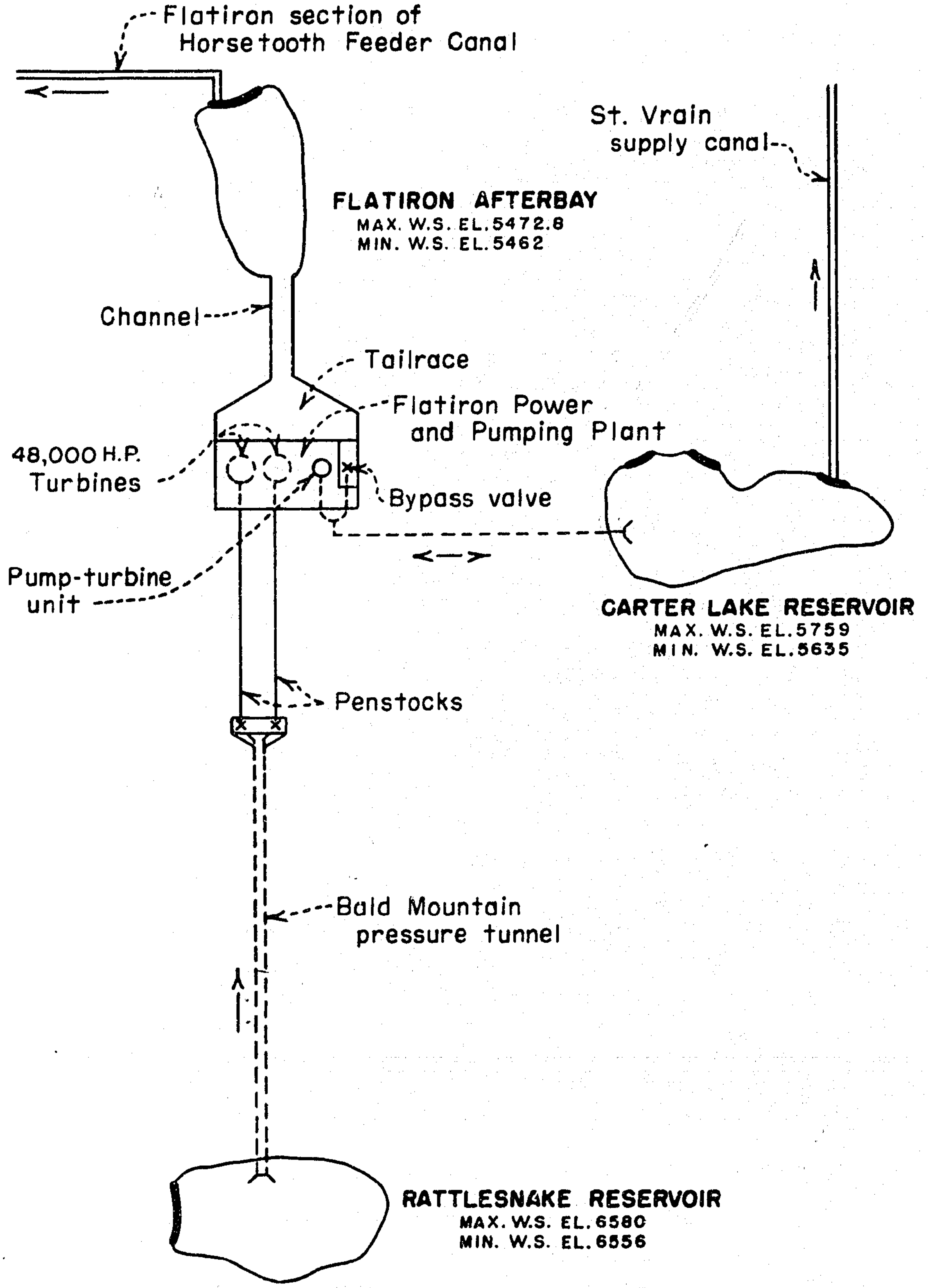
FLATIRON POWER AND PUMPING PLANT

GENERAL ARRANGEMENT

TRANSVERSE SECTIONS THRU ℄ UNIT 3 AND THRU VALVE STRUCTURE

DRAWN H.L.T. SUBMITTED
TRACED A.R.P. RECOMMENDED
CHECKED APPROVED
DENVER, COLORADO, NOVEMBER 30, 1950

245-D-5949



FLATIRON POWER AND PUMPING PLANT
BYPASS VALVE STILLING BASIN STUDIES
SCHEMATIC FLOW DIAGRAM

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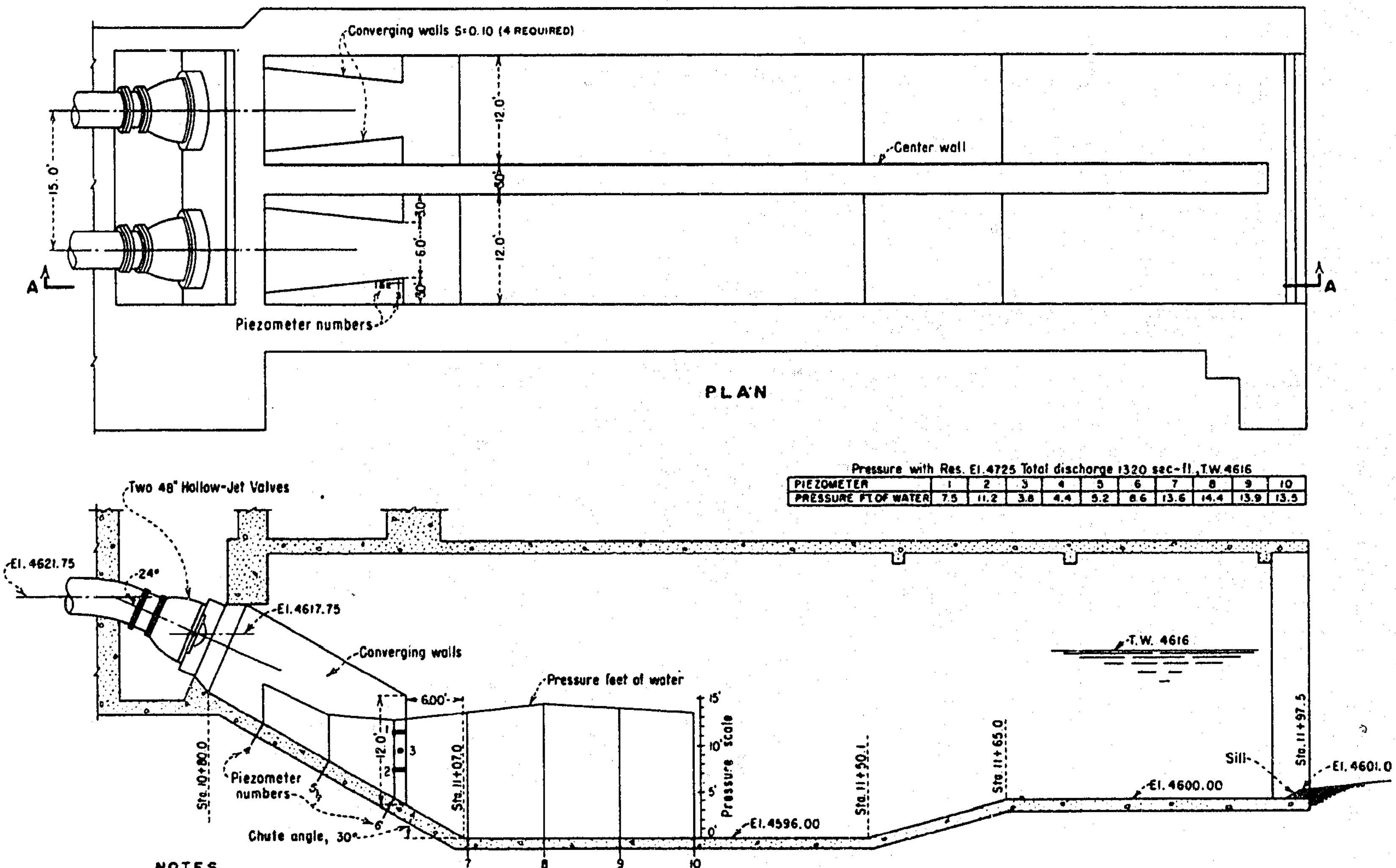
FIGURE 5
Report Hyd. 328



Pressure with Res. El. 4725 Total discharge 1320 sec-ft., T.W. 4616

PIEZOMETER	1	2	3	4	5	6	7	8	9	10
PRESSURE FT. OF WATER	7.5	11.2	3.8	4.4	5.2	8.6	13.6	14.4	13.9	13.5

NOTES

1. See Report Hyd. 283, "Hydraulic Model Studies of the Outlet Works - Boysen Dam, Missouri River Basin Project."
2. Dimensions, Elevations and other details are for Boysen Dam Outlet Works.

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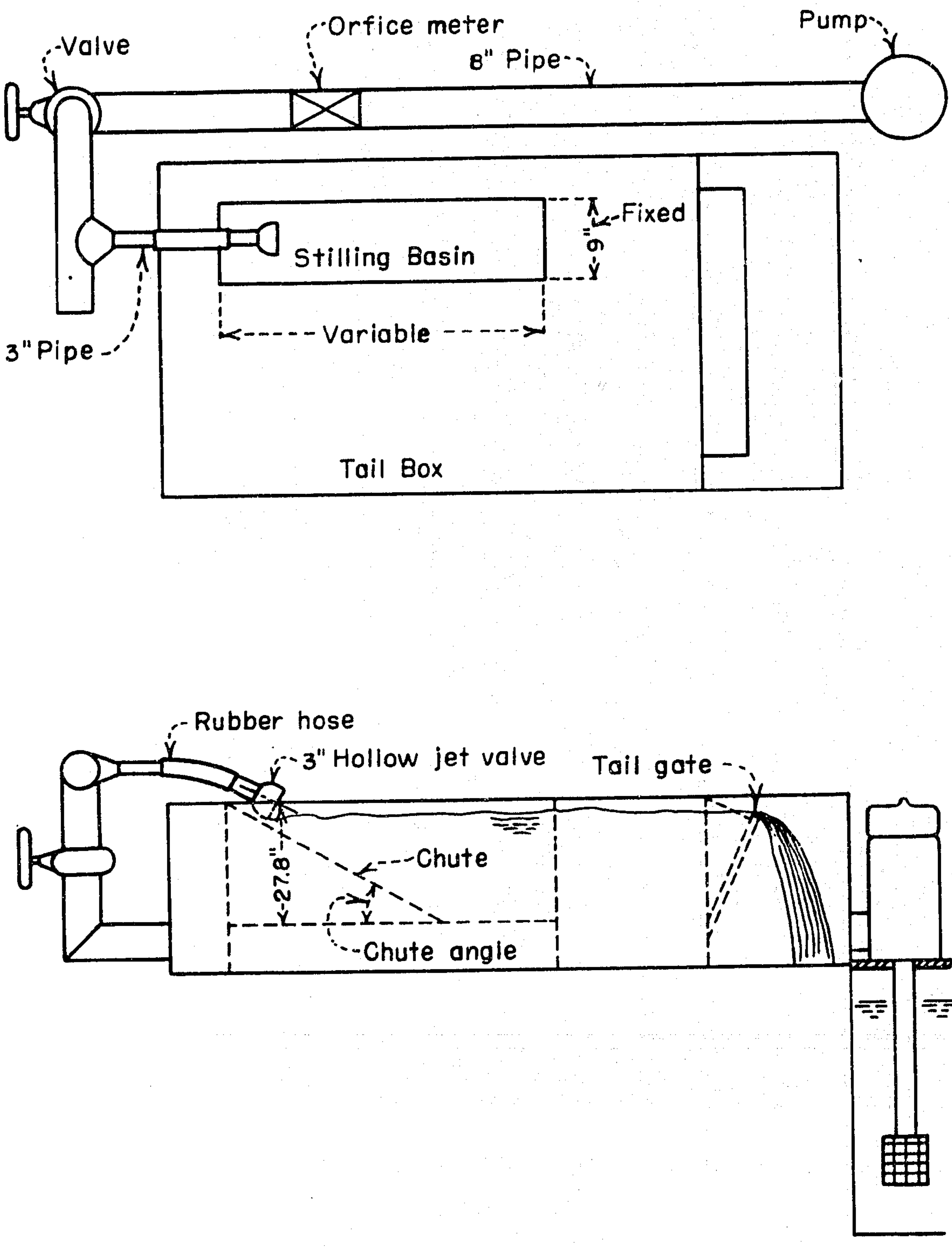
FLATIRON POWER AND PUMPING PLANT
BYPASS VALVE STILLING BASIN STUDIES
UNSUBMERGED JET STILLING BASIN - BOYSEN DAM OUTLET WORKS



FLATIRON POWER AND PUMPING PLANT
BYPASS VALVE STILLING BASIN STUDIES
STILLING BASIN FOR AN UNSUBMERGED JET
1:12 Scale model

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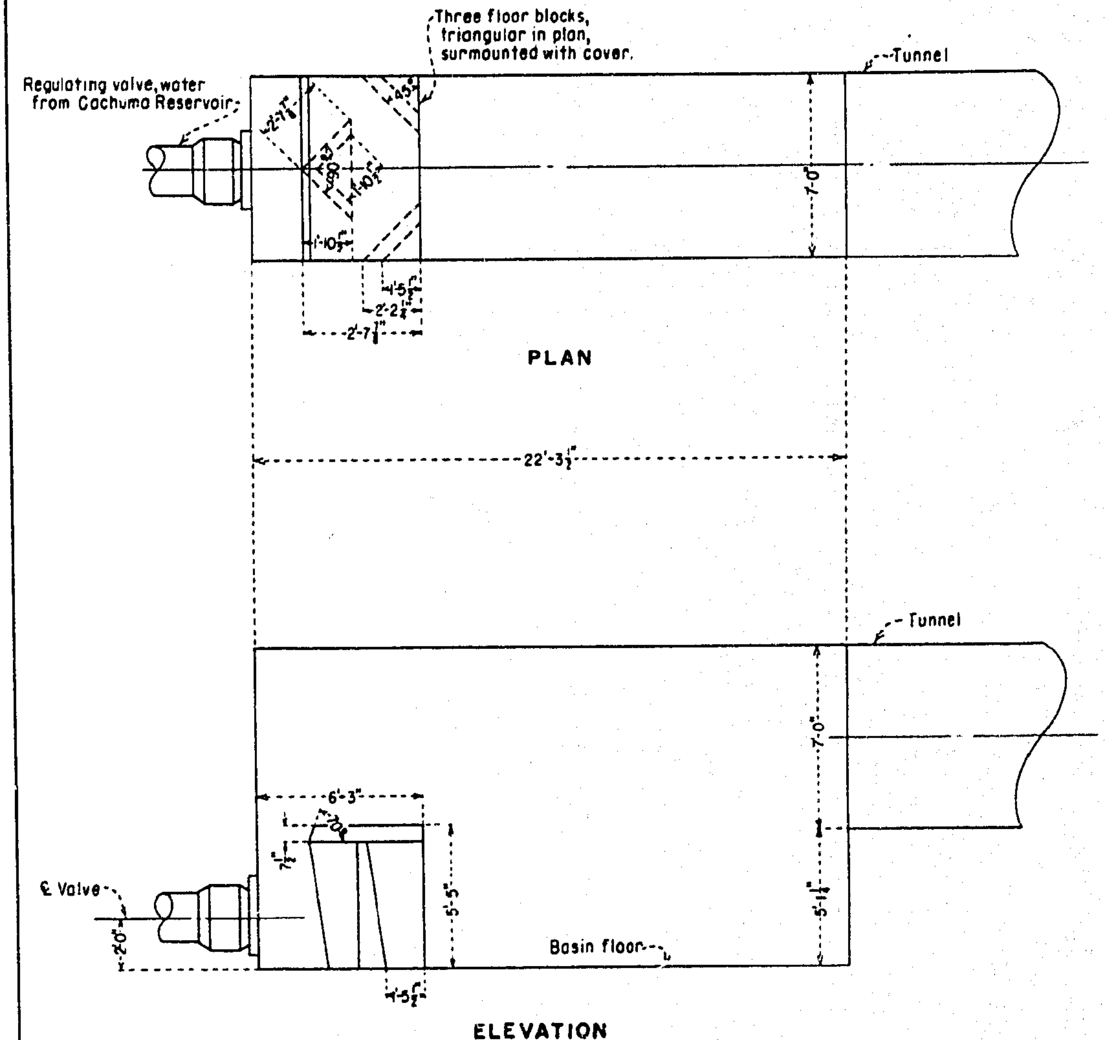
FIGURE 7
Report Hyd. 328



NOTES

1. The outlet from Cachuma Reservoir into Tecolote Tunnel is required to release a maximum flow of 100 CFS. at heads between 20 and 104 feet
2. See Report Hyd. 287, "Hydraulic Model Studies of Methods to Dissipate the High Velocity Jet From the Regulating Valve in Tecolote Tunnel-Santa Barbara Project, California."

FLATIRON POWER AND PUMPING PLANT
BYPASS VALVE STILLING BASIN STUDIES
SUBMERGED JET STILLING BASIN STUDIED FOR TECOLOTE TUNNEL

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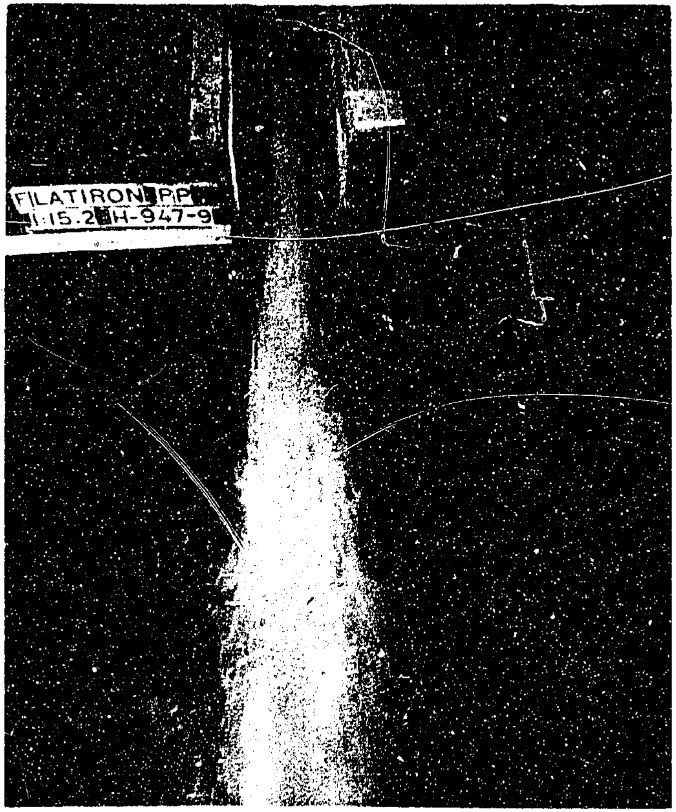
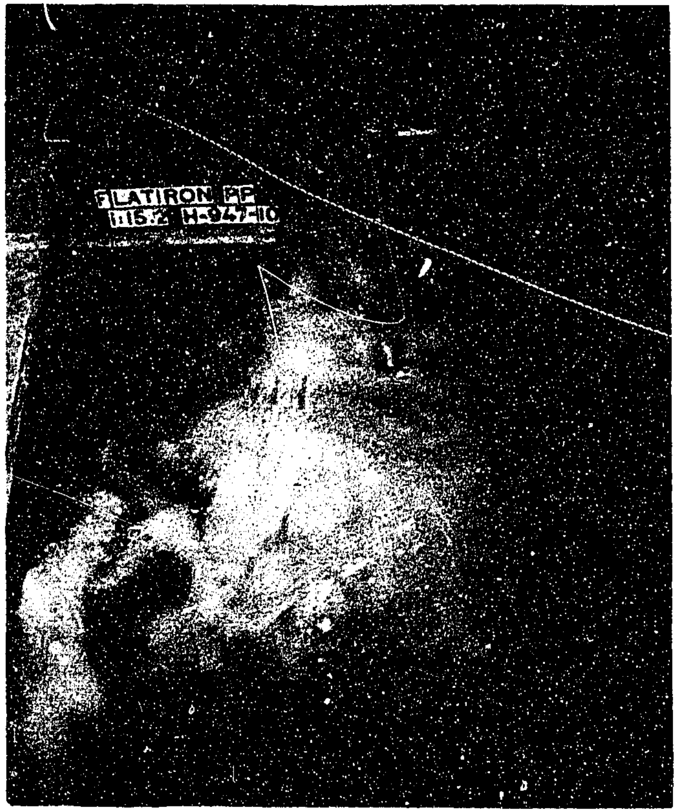


(A) Valve discharging into a basin without tailwater.

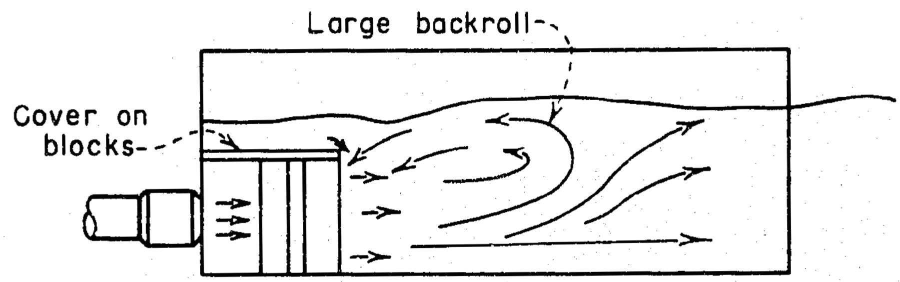


(B) Valve discharging into basin with minimum tail-water elevation 5462.

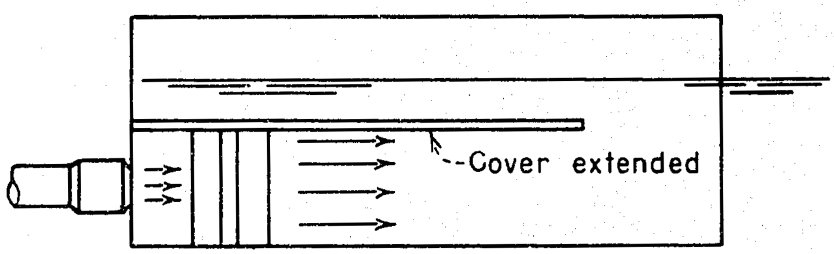
FLATIRON POWER AND PUMPING PLANT
BYPASS VALVE STILLING BASIN STUDIES

Valve Discharging With and Without Tailwater in a Stilling Basin for a submerged Jet 500 cfs Flow and 260 Feet Head on Centerline of 42-inch Tube Valve 71% Open.
1:15.2 Scale Model

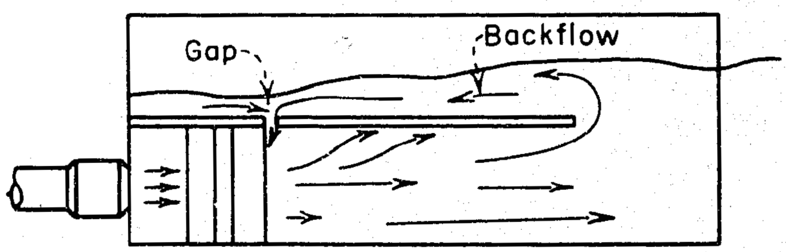
FIGURE 8
Report Hyd. 328



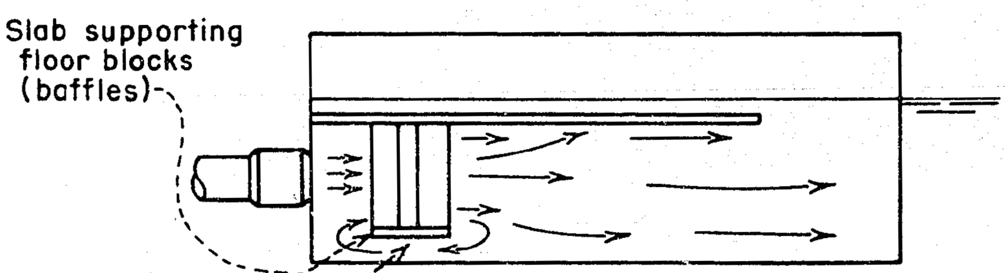
(A) INITIAL BASIN WITH LARGE BACKROLL AND ROUGH WATER SURFACE



(B) BASIN WITH COVER ON FLOOR BLOCKS EXTENDED GIVING A SMOOTH WATER SURFACE



(C) COVER WITH A GAP SHOWING LOWER PRESSURE EXISTED BENEATH COVER



(D) PASSAGE FOR THE REENTRANCE OF WATER TO THE LOW PRESSURE REGION

FLATIRON POWER AND PUMPING PLANT

BYPASS VALVE STILLING BASIN STUDIES

SCHEMATIC SKETCHES—SUBMERGED JET STILLING BASIN DEVELOPMENT

1:15.2 Scale model

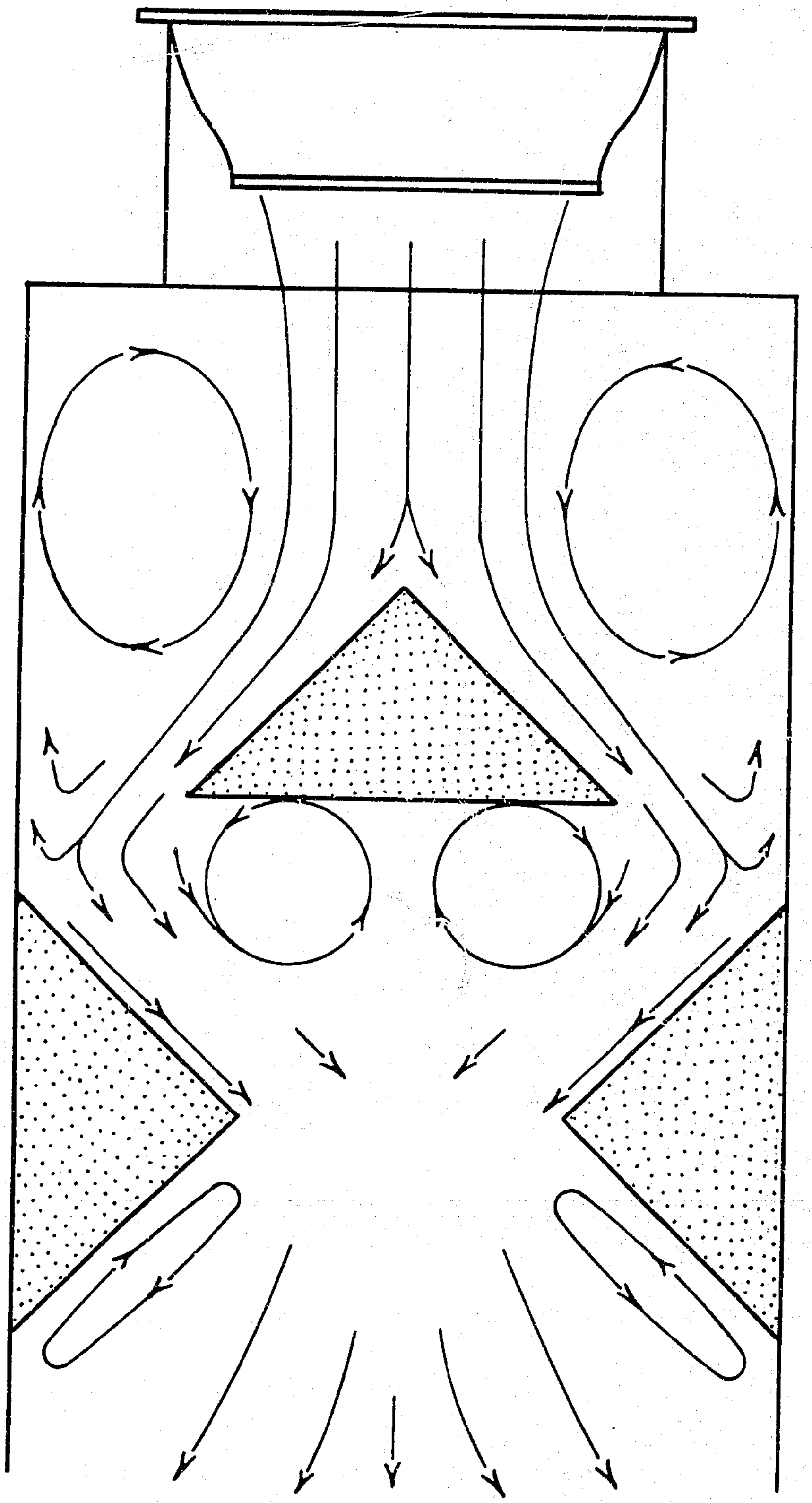
422

(A) Stilling basin with 42-inch tube valve discharging submerged. Flow, 500 cfs. Head, 260 feet. Tail-water elevation, 5467 feet. 1:15.2 scale model.

(B) Stilling basin with 42-inch hollow jet valve discharging unsubmerged. Flow, 500 cfs. Head, 260 feet. Tail-water elevation, 5470 feet. 1:14 scale model.

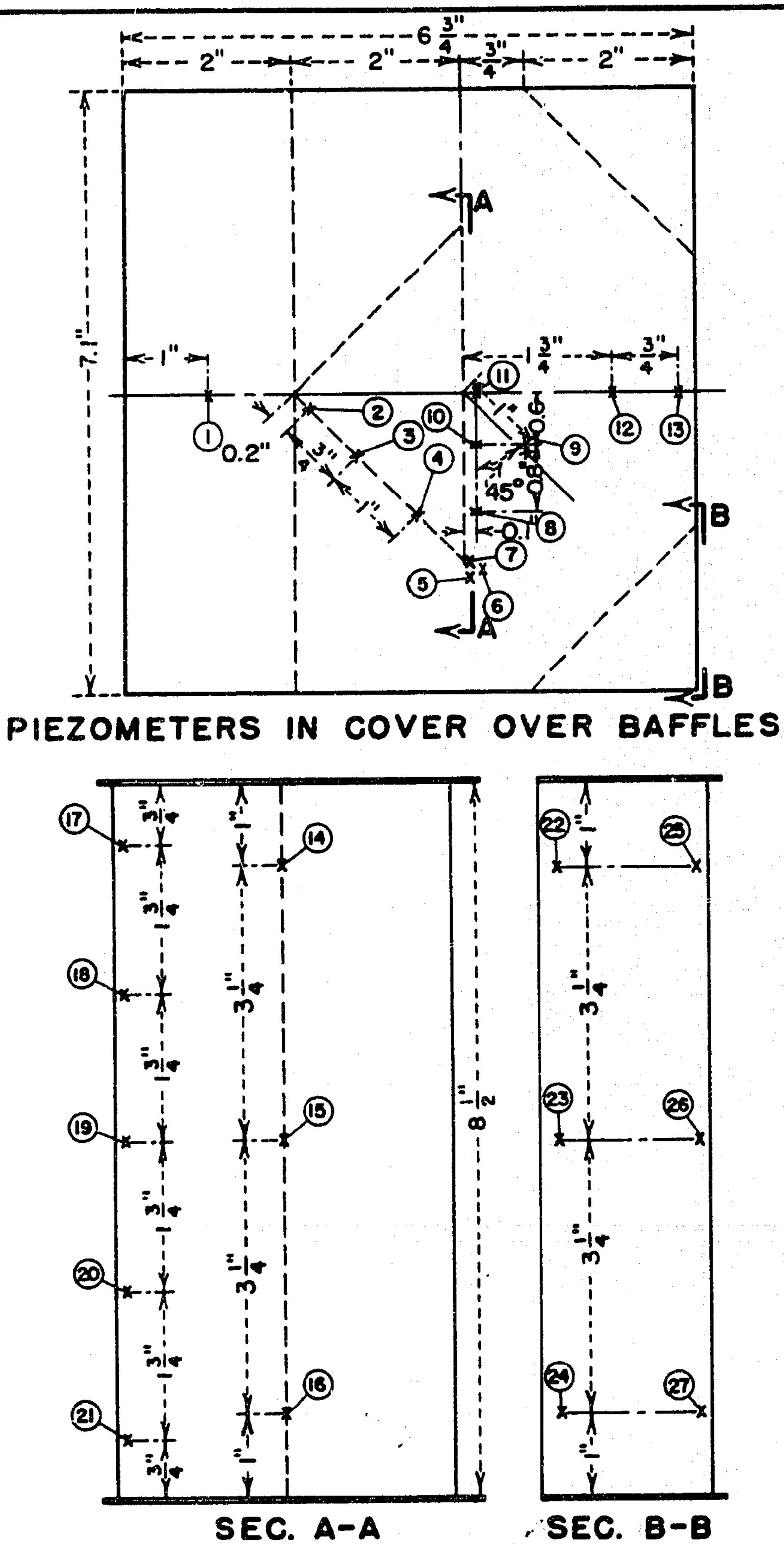
FLATIRON POWER AND PUMPING PLANT
BYPASS VALVE STILLING BASIN STUDIES

Comparison of Water Surfaces of Stilling Basins with a Submerged and Unsubmerged Jet at Comparable Operating Conditions.



FLATIRON POWER AND PUMPING PLANT
BYPASS VALVE STILLING BASIN STUDIES
SCHEMATIC FLOW DIAGRAM THROUGH BASIN BAFFLES
VIEWED FROM TRANSPARENT COVER OVER BAFFLES
1:15.2 Scale model

422



FLATIRON POWER AND PUMPING PLANT
BYPASS VALVE STILLING BASIN STUDIES
BASIN PIEZOMETER LOCATIONS - TESTS 1, 2, 3, AND 4
1:15.2 Scale model

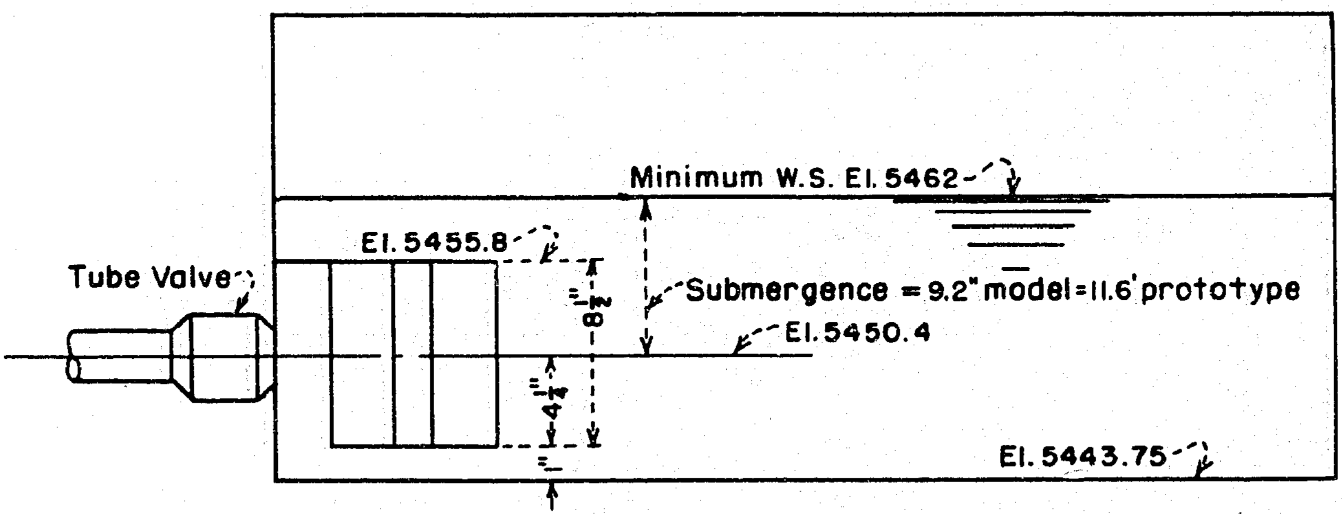
422

FIGURE 14
Report Hyd. 328

Piezometer Number (See Figure 12)	Run 1 Q 500 H 252	Run 2 Q 566 H 143	Run 3 Q 656 H 394	Run 4 Q 764 H 308	Run 5 Q 500 H 476
1	6.2	6.8	6.8	8.4	5.3
2	6.4	7.1	9.4	9.9	6.4
3	13.2	13.6	13.4	13.2	13.2
4	9.9	--	9.9	13.4	4.6
5	--	--	--	--	--
6	3.8	4.3	1.5	2.3	-0.3
7	3.8	3.8	2.3	3.0	1.2
8	-3.5	-1.5	-9.9	-8.8	-7.6
9	-4.3	-3.3	-8.4	-8.1	-6.1
10	-2.0	0.0	-7.1	-6.8	-4.6
11	1.8	2.0	-1.5	-1.5	0.0
12	6.8	7.6	3.8	1.8	5.3
13	--	--	--	--	--
14	4.3	4.1	2.0	0.8	3.5
15	7.6	8.7	4.6	4.6	5.8
16	11.7	12.0	8.7	7.9	9.3
17	-2.0	-0.4	-8.1	-7.6	-6.5
18	2.7	4.1	-2.3	-1.0	-0.8
19	6.4	7.4	2.3	3.0	3.0
20	7.1	8.7	2.0	2.7	3.8
21	6.5	9.0	-0.8	0.7	0.4
22	7.0	6.2	5.8	5.8	6.5
23	10.8	10.3	9.7	9.4	10.3
24	14.0	14.1	12.5	12.4	13.2
25	6.8	6.2	5.8	5.6	6.2
26	10.8	10.3	9.4	8.7	10.2
27	14.6	14.4	12.9	12.5	13.2

All model data converted to prototype values. Water passage beneath baffles open. Pressures are in feet of water. Q is discharge in cfs. H is total head on valve centerline in feet of water. Minimum Tail-water elevation, 5462, in all runs. Piezometers not recorded had high positive pressures.

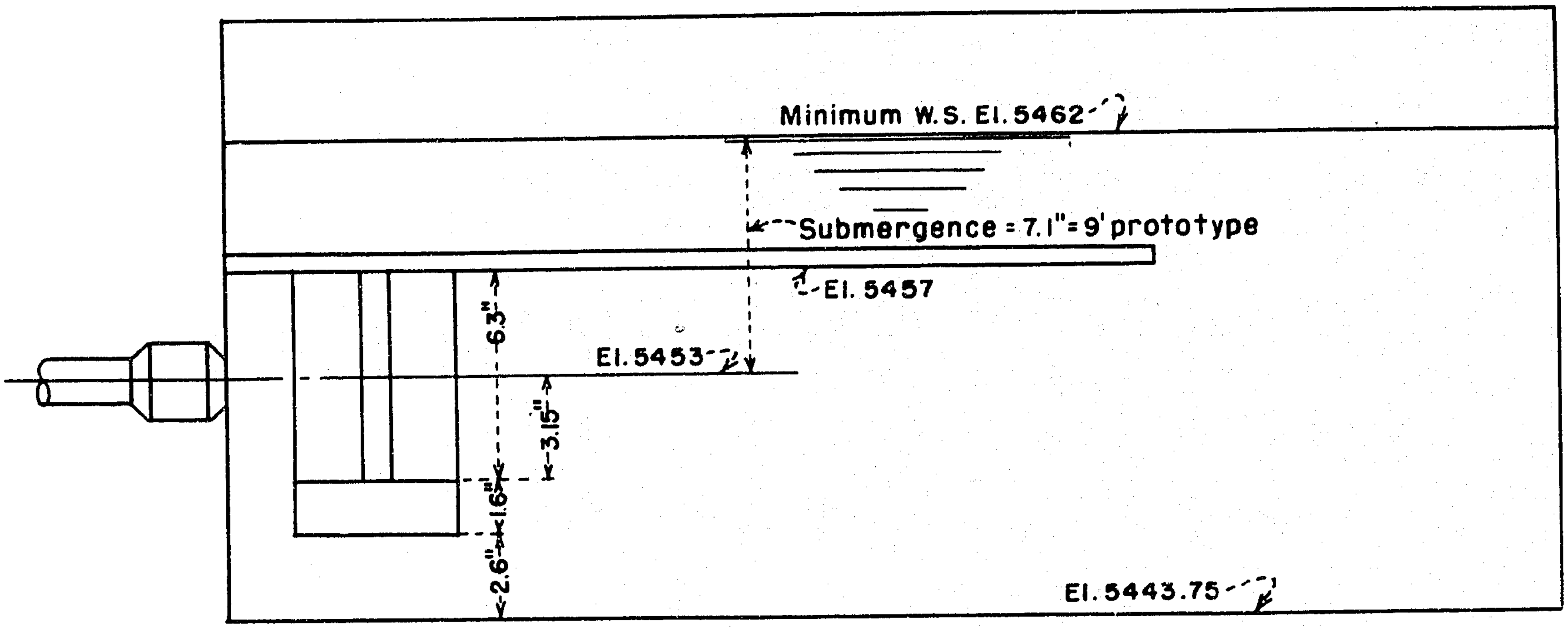
FLATIRON POWER AND PUMPING PLANT
BYPASS VALVE STILLING BASIN STUDIES
Basin Pressures for Test 1



FLATIRON POWER AND PUMPING PLANT
BYPASS VALVE STILLING BASIN STUDIES
MODEL ARRANGEMENT FOR DETERMINING BASIN WATER PRESSURES, TEST 1
1:15.2 Scale model

Report Hyd. 328 FIGURE 13

422



FLATIRON POWER AND PUMPING PLANT
BYPASS VALVE STILLING BASIN STUDIES
MODEL ARRANGEMENT FOR DETERMINING BASIN WATER PRESSURES, TEST 3
1:15.2 Scale model

Piezometer Number (See Figure 12)	Run 1 Q 500 H 252	Run 2 Q 656 H 394	Run 3 Q 764 H 308	Run 4 Q 500 H 476
8	-3.8	-9.1	-9.9	-7.1
9	-7.6	-15.5	-15.6	-11.1
10	-1.5	-6.5	-6.8	-3.3
11	2.3	-1.5	-1.5	1.1
12	6.1	5.3	9.1	6.1
17	-2.3	-7.9	-8.1	-7.4

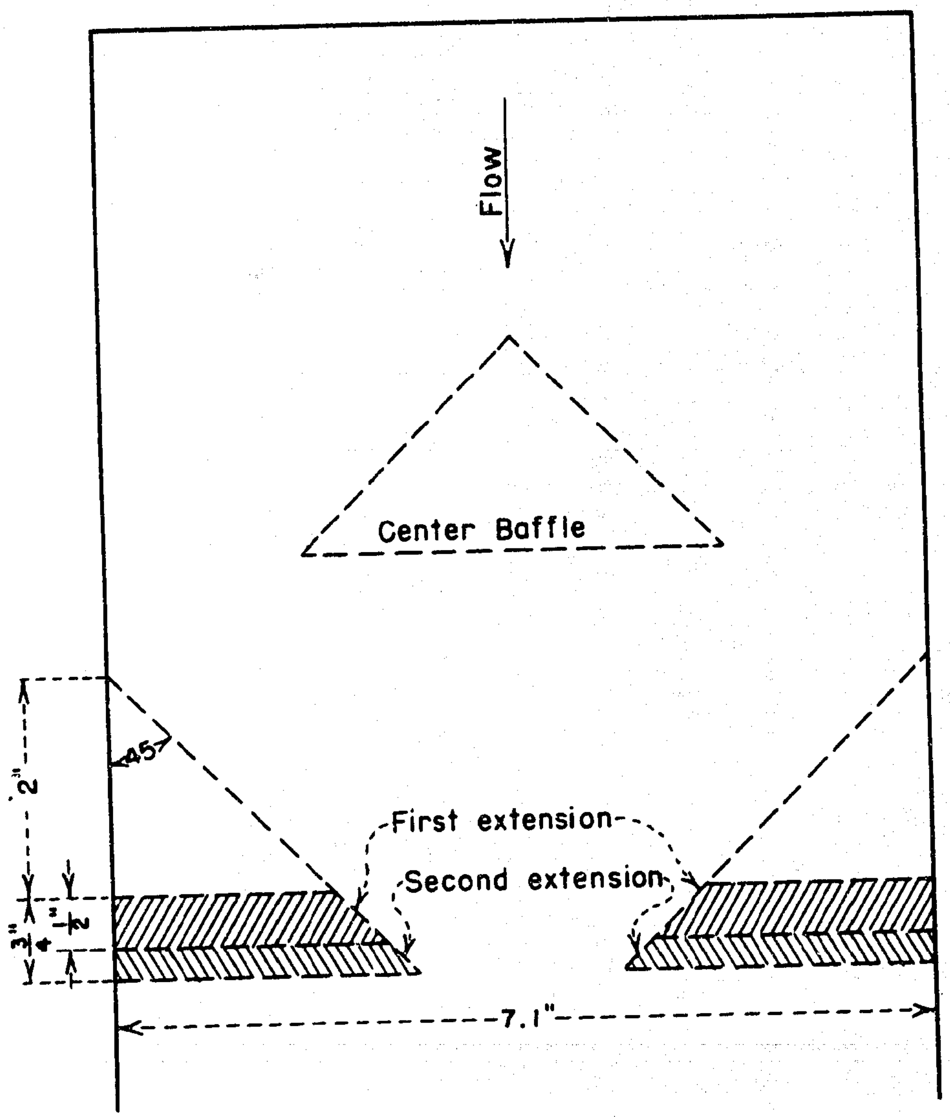
(A) Test 2. Water passage beneath baffles closed.

1	5.0	10.3	10.3	9.6
8	-4.9	-9.4	-11.7	-7.1
9	-8.7	-15.5	-17.0	-10.9
10	-3.3	-7.9	-9.4	-6.4
11	-1.1	-4.9	-4.1	-3.3
12	-1.8	-7.9	-3.3	-6.4
17	-3.3	-8.7	-9.4	-5.6
22	5.5	4.7	3.9	5.5
23	9.6	8.8	8.1	8.8
25	5.5	4.7	3.9	4.7
26	9.6	8.8	8.1	8.8

(B) Test 3. Water passage beneath baffles increased from 1.27 to 3.29 feet high.

Note: All model data converted to prototype values. Pressures are in feet of water. Q is discharge in cfs. H is total head on valve centerline in feet of water. Minimum tail-water elevation, 5462, in all runs.

FLATIRON POWER AND PUMPING PLANT
BYPASS VALVE STILLING BASIN STUDIES
Basin Pressures for Tests 2 and 3



FLATIRON POWER AND PUMPING PLANT
BYPASS VALVE STILLING BASIN STUDIES
BASIN SIDE BAFFLE EXTENSIONS, TEST 4
1:15.2 Scale model

FIGURE 18
Report Hyd. 328

Piezometer (See Figure 12)	Run 1	
	7.6" extension (prototype length)	11.4" extension (prototype length)
1	5.0	--
8	-6.4	--
9	-10.2	-10.9
10	-5.6	--
11	-3.3	--
12	-1.8	--

(A) Test 4. Pressures with side baffle extensions shown on Figure 17.

Piezometer (See Figure 19)	Run 1
1A	5.6
2A	5.6
3A	9.7
4A	9.7

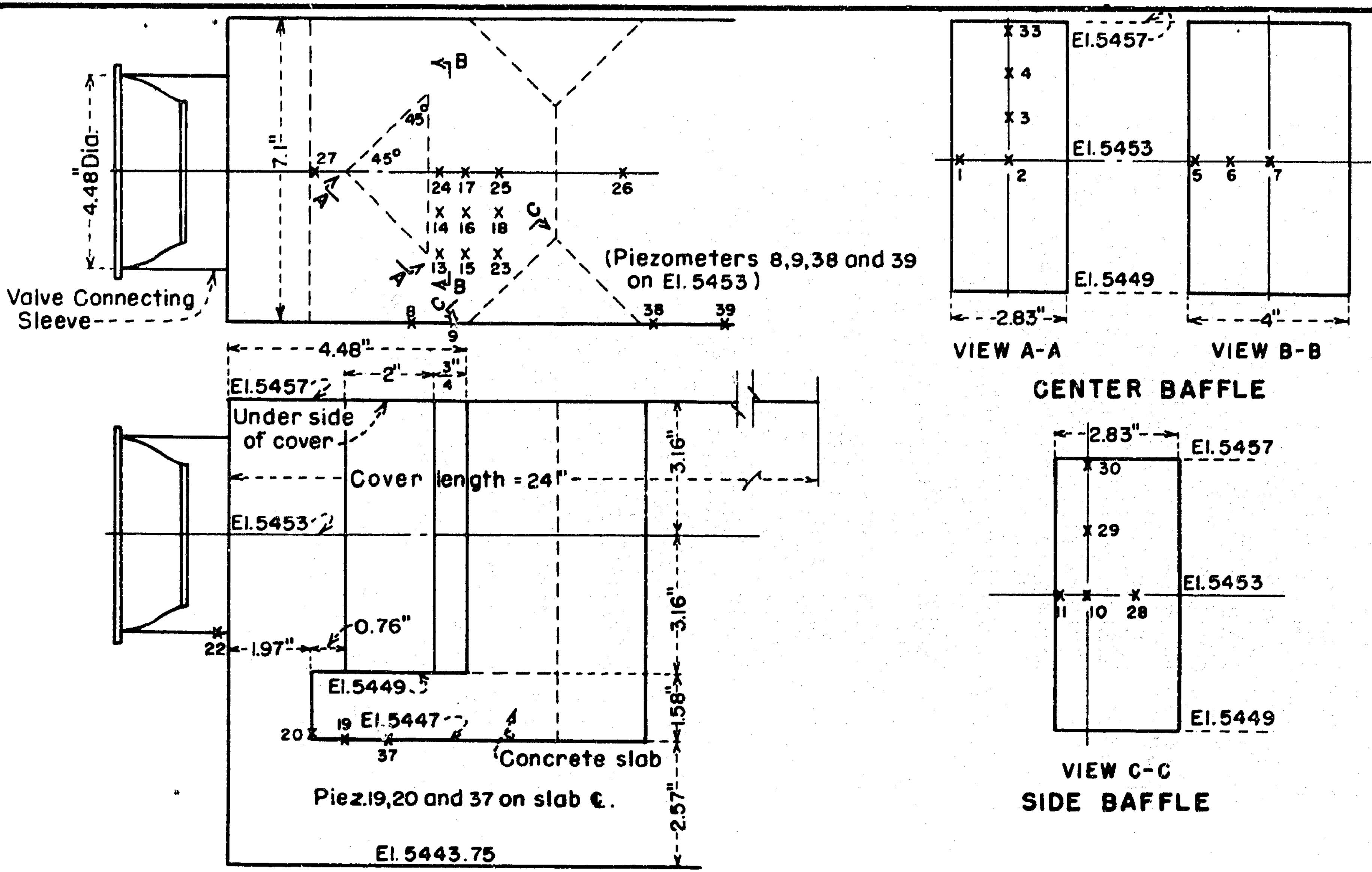
(B) Test 5. Pressures with side baffles having 90° corners.

Piezometer (See Figure 20)	Run 1	Run 2	Piezometer (See Figure 20)	Run 1	Run 2
1	123.3	196.7	21	--	--
2	30.1	42.4	22	14.4	16.0
3	18.7	70.8	23	2.3	0.5
4	9.7	11.2	24	-1.7	-5.3
5	6.4	3.5	25	-2.0	-8.7
6	7.6	5.3	26	11.1	6.4
7	10.2	8.8	27	9.1	10.9
8	13.2	13.8	28	26.0	32.1
9	6.2	--	29	-2.6	-9.0
10	0.9	-6.7	30	6.1	4.9
11	0.3	-7.4	31	--	--
12	--	--	32	--	--
13	0.8	-4.7	33	41.9	46.5
14	-4.4	-11.4	34	--	--
15	2.3	-3.0	35	--	--
16	-7.7	-16.0	36	--	--
17	-6.4	-13.7	37	16.3	14.1
18	-3.6	-10.6	38	7.7	7.4
19	14.3	13.5	39	8.5	7.7
20	14.6	13.8			

(C) Test 6. Pressures with basin baffles moved 1 foot further upstream and valve connecting sleeve as shown on Figure 21.

Note: All model data converted to prototype values. Pressures are in feet of water. Q is discharge in cfs. H is total head on valve centerline in feet of water. Minimum tail-water elevation, 5462, in all runs.
Run 1: Q = 500, H = 252. Run 2: Q = 656, H =394.

FLATIRON POWER AND PUMPING PLANT
BYPASS VALVE STILLING BASIN STUDIES
Basin Pressures for Tests 4, 5, and 6



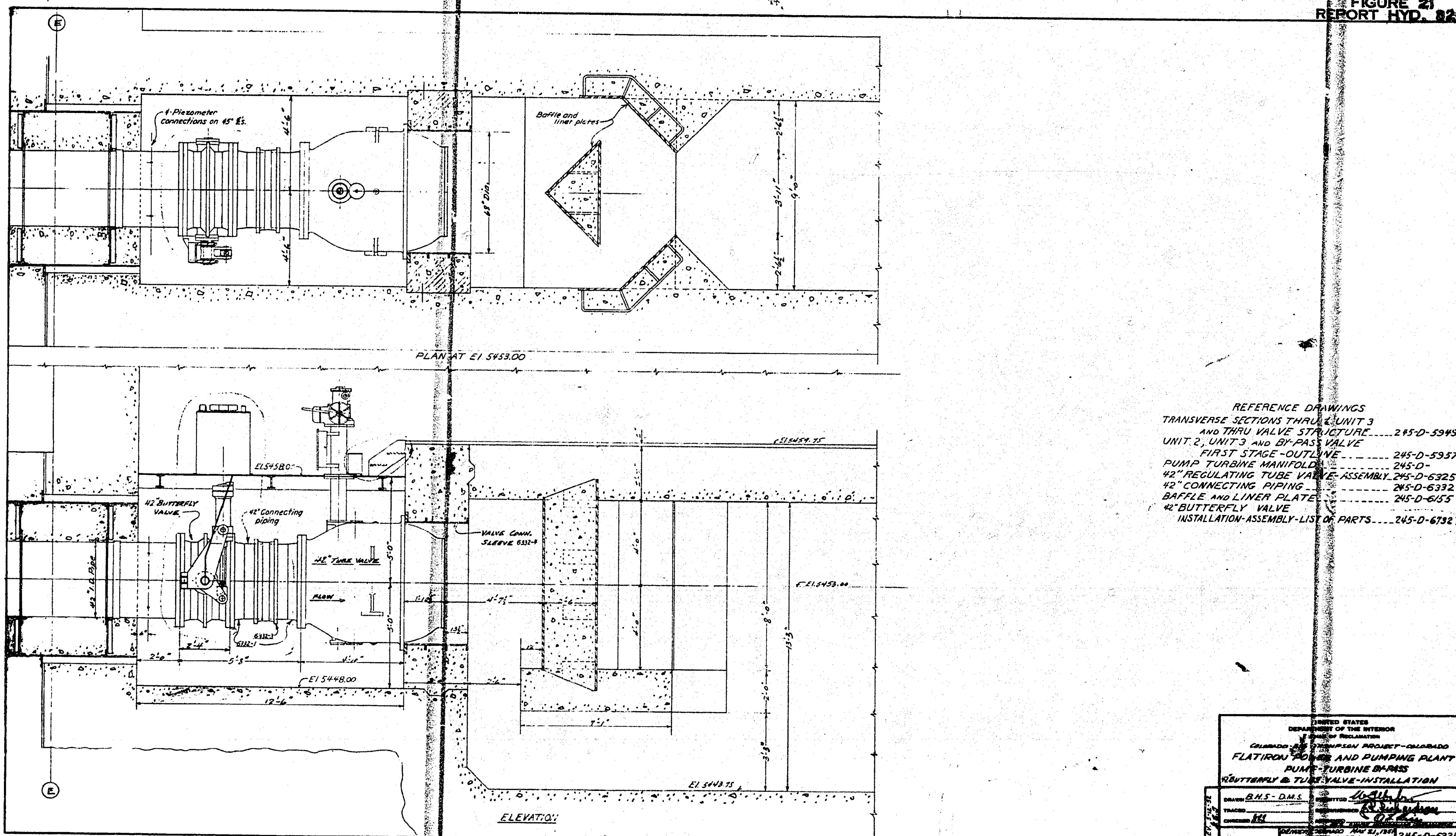
FLATIRON POWER AND PUMPING PLANT

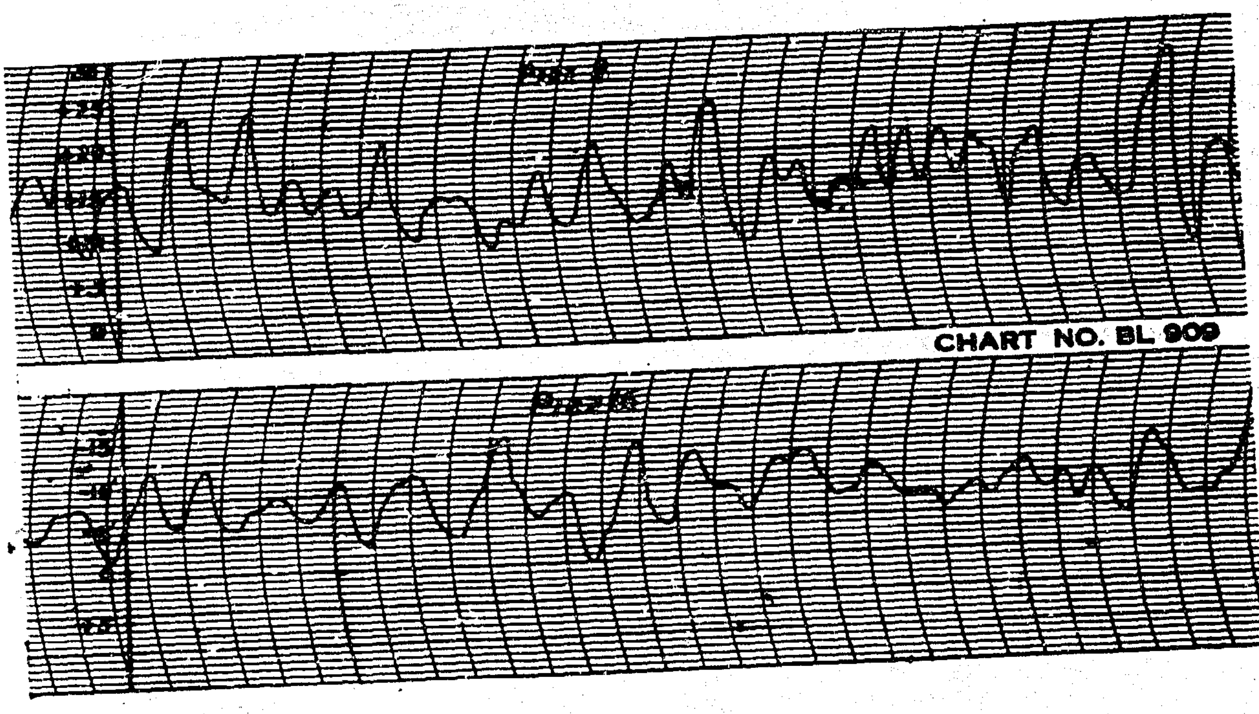
BYPASS VALVE STILLING BASIN STUDIES

RECOMMENDED STILLING BASIN DESIGN AND BASIN PIEZOMETER LOCATIONS, TEST 6

1:15.2 Scale model

422


4-Piezometer connections on 45° ℄s.
Baffle and liner plates
68" Dia.
PLAN AT El 5453.00
42" Butterfly valve
42" Connecting piping
42" Tube valve
FLOW
Valve conn. sleeve 6332-4
El 5458.00
El 5454.75
El 5453.00
El 5448.00
El 5443.75
42" I.D. Pipe
ELEVATION
REFERENCE DRAWINGS
TRANSVERSE SECTIONS THRU ℄ UNIT 3 AND THRU VALVE STRUCTURE ---- 245-D-5949
UNIT 2, UNIT 3 AND BY-PASS VALVE FIRST STAGE-OUTLINE ---- 245-D-5957
PUMP TURBINE MANIFOLD ---- 245-D-
42" REGULATING TUBE VALVE-ASSEMBLY 245-D-6325
42" CONNECTING PIPING ---- 245-D-6332
BAFFLE AND LINER PLATE ---- 245-D-6155
42" BUTTERFLY VALVE INSTALLATION-ASSEMBLY-LIST OF PARTS ---- 245-D-6732
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO-BIG THOMPSON PROJECT-COLORADO
FLATIRON POWER AND PUMPING PLANT
PUMP-TURBINE BY-PASS
42" BUTTERFLY & TUBE VALVE-INSTALLATION
DRAWN B.H.S - D.M.S.
TRACED
CHECKED
DENVER, COLORADO MAY 21, 1951
SHEET 1 OF 1
245-D-6324



Flow, 500 cfs; head on valve center line, 252 feet; tailwater elevation, 5462; pressure scale in feet of water prototype; average pressures agree with those on Figure 18c.

FLATIRON POWER AND PUMPING PLANT
BYPASS VALVE STILLING BASIN STUDIES

Oscillograph Traces from Pressure Cells Attached to Piezometers 8 and 16, Test 6.

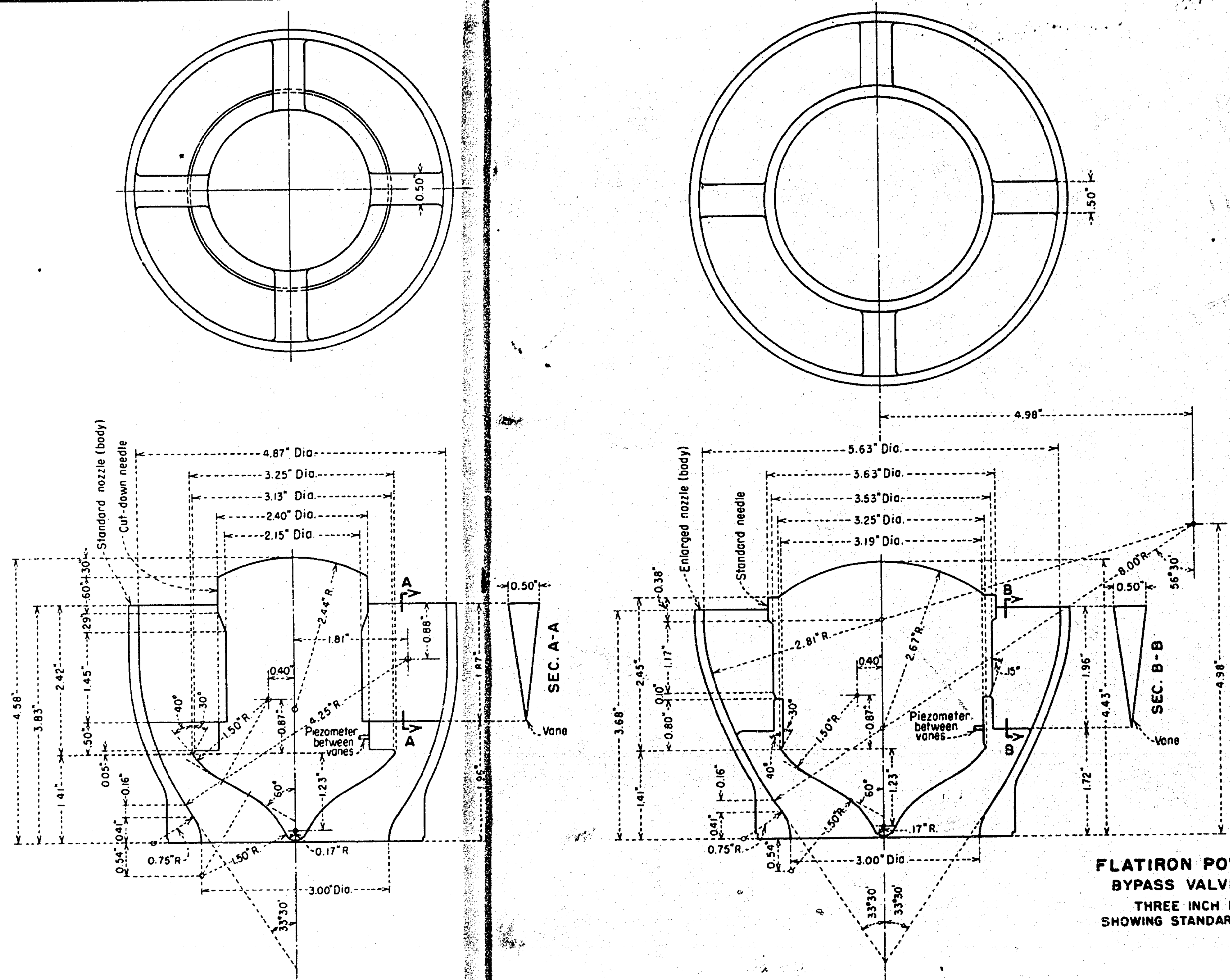
FIGURE 23
Report Hyd. 328

(A) Flow of 500 cfs with 260 feet head at valve inlet 42-inch tube valve 71% open of full valve travel. This is maximum flow and head expected in the field.

(B) Flow of 900 cfs with 350 feet head at valve inlet. 42-inch tube valve full open. This flow and head are greater than is expected in the field.

FLATIRON POWER AND PUMPING PLANT
BYPASS VALVE STILLING BASIN STUDIES

Water Surface Conditions of Recommended Stilling Basin Design.
Tailwater Elevation 5467
1:15.2 Scale Model



(A) VALVE WITH CUT-DOWN NEEDLE

(B) VALVE WITH ENLARGED NOZZLE

FLATIRON POWER AND PUMPING PLANT
BYPASS VALVE STILLING BASIN STUDIES
THREE INCH MODEL OF HOLLOW JET VALVE SHOWING STANDARD AND REVISED NEEDLE AND NOZZLE

Run	Total head (1 diameter upstream of valve) feet water	Flow cfs	Submergence of jet ℄, feet	Pressure on needle downstream of control section, feet
1	129	455	0	0
2	106	504	13.5	-47.6
3	109	502	18.7	-44.5
4	116	500	27.0	-40.7

(A) Hollow-jet valve with a cut-down needle (Figure 24A). Valve full open.

1	31.4	340	0	0
2	47.5	475	0	0
3	45.9	476	13	-11.4
4	49.2	500	13	-11.7

(B) Hollow-jet valve with a cut-down needle and enlarged nozzle (Figure 24B). Valve full open.

1	168	425	6.4	-29.4
2	125	355	9.0	-20.0
3	132	350	0	
4	185	417	0	
5	157	385	0	

(C) Hollow-jet valve with a cut-down needle and enlarged nozzle (Figure 24). Valve 55 percent open.

FLATIRON POWER AND PUMPING PLANT
BYPASS VALVE STILLING BASIN STUDIES
Needle Pressures Downstream of Control Section--Hollow-jet Valve
1:12 Scale Model